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Wireless Smart Electric Power Management System Based On MEMS Technology

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ABSTRACT

TARDEC has identified a need for more efficient and compact electrical power systems in military vehicles. This paper describes a neural electrical management system that will accomplish this by utilizing the power consumption characteristic of each controlled subsystem, and its required performance, as input for a control algorithm that optimizes the distribution of available on-board power. By utilizing radio communication and on-location control, the system would drastically reduce vehicle-wiring requirements and could result in smaller, less expensive, on-board computers (system managers). Additionally, the system, by continuously monitoring/assessing all systems, will alert vehicle operators and mission planners and provide them with critical decision making information. The, system would also, allow for easily reconfigurable electric subsystems and power distribution schedule changes via operational software updates.

INTRODUCTION

In recent years military technology has experienced a strong increase in the use of electronic and electrical systems. This trend is continuing. Military vehicles serve as platforms for a variety of mobile battlefield systems such as missile launchers, radars and digitized battlefield systems. These systems place an ever-increasing demand on electrical power. The main suppliers of power are on-board batteries that are charged by the alternator system of the vehicle. The available power on board a vehicle is therefore limited and changes with time and temperature. The existing supply of power from the vehicle is severely stressed if several electrical subsystems operate simultaneously and sufficient energy or a secondary source must be available at all times to start and operate the vehicle in all climatic conditions, especially arctic.

More and better performing batteries could be installed at a penalty of substantially increased weight and much higher cost to provide more power. Vehicle design changes would be needed to provide space for more batteries. Therefore, the optimization of power distribution between the various loads on board the vehicle as well as an increase of the efficiency of already installed batteries by better battery charge control, is attractive and applies to any battery and power distribution system.

Power management allows the continued operation of electrical subsystems even at depressed levels of battery power and stored capacity, by making more efficient use of the available power and energy. Power management will help if the power needed for an electrical subsystem permits operation of the subsystem within a bandwidth of power levels and/or the power requested by the subsystem is time dependent. In the first case, the subsystem may be maintained in a functional state even at lower power levels. In the second case, the power distribution can possibly be timed such that overlapping power demands do not exceed the maximum available power from the battery at any time during the operation.

Micron Corporation, under contract to TACOM, is developing a system that optimizes the use of installed power in vehicles using a novel neural control system (NPC) to handle complex control functions and MEMS technology to drastically reduce the cost of the control hardware. This paper presents a description of the proposed power management system.

CONCEPT AND GENERAL STRATEGY OF THE POWER MANAGEMENT SYSTEM

To improve the operating conditions for electrical systems, a two-pronged approach is taken: by optimizing charge control for the battery, the amount of energy and power available from the battery is

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14. ABSTRACT
TARDEC has identified a need for more efficient and compact electrical power systems in military vehicles. This paper describes a neural electrical management system that will accomplish this by utilizing the power consumption characteristic of each controlled subsystem, and its required performance, as input for a control algorithm that optimizes the distribution of available on-board power. By utilizing radio communication and on-location control, the system would drastically reduce vehicle-wiring requirements and could result in smaller, less expensive, on-board computers (system managers). Additionally, the system, by continuously monitoring/assessing all systems, will alert vehicle operators and mission planners and provide them with critical decision making information. The, system would also, allow for easily reconfigurable electric subsystems and power distribution schedule changes via operational software updates.

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increased, and by optimizing the power distribution among the various loads of the vehicle, the power consumption will be managed and directed where it is needed most thus keeping the vehicle and its needed subsystems operational longer while stretching battery capacity.

The hardware of the power management system consists of a single wire power distribution network and a wireless signal distribution network.

The system manages individual electrical loads by employing a single chip control system for each load. As is shown below, this drastically reduces the amount of wiring needed for power distribution and control and greatly simplifies installation, maintenance and troubleshooting of electric subsystems, thus reducing the cost of installing these systems and of maintaining the vehicle.

The basis for control is the analysis of the power consumption characteristic for each subsystem, the needed performance and the available power from the battery. The objective of power control optimization is to keep the power consumption below the available power level and to minimize the system energy consumption.

The control system calls for a high level of component integration by applying MEMS technology. This is expected to result in smaller, less expensive, on board computers (system managers). By continuously monitoring and assessing all electrical loads, the power management system provides vehicle operators and mission planners with critical decision making information.

The system allows for easily reconfigurable electric subsystems and power distribution schedule changes via operational software updates and a neural learning algorithm. More electrical subsystems can be added and are automatically included in the control and management system by simply connecting them to the single wire power bus.

POWER MANAGEMENT ARCHITECTURE

This section discusses the underlaying load structures and their relationships to the proposed power management strategy.

An analysis of electrical loads on a vehicle reveals that the power required by almost all electric subsystems is time dependent (and time limited) and allows operation within a significant bandwidth of power. For each subsystem the power demand can be described by a time dependent power function, P(t), with a lower and upper time limit. The lower limit idicates when the subsystem is switched on. The upper limit indicates when the subsystem is switched off. The shape of the function depends on the operating characteristic of the device and is therefore device dependent. The energy consumption of each subsystem is the integral of the power function.

Switching on a load draws current from the battery and reduces the battery voltage. More power demand results in a strong additional current increase and a moderate additional voltage decrease. If more than one load is switched on simultaneously, the current increases and the voltage decreases, in the same way as for a single device with a power demand of the two devices together.

The limit of available power is reached, when the battery voltage under load has reached a current specific lower limit. When the battery is fully charged, large amounts of current can, for short times, be discharged before the voltage limit is reached. If the battery is partially discharged, then the battery voltage might reach the voltage limit immediately and is then not able to supply the requested power even though sufficient energy might be available to support an opperating cycle.

With the vehicle engine running, the alternator supplies current to the battery at a voltage that is slightly higher than open battery voltage. If a load is connected to the battery, the generated power passes through the battery to the load and reduces the battery discharge under load. However, the additional power and energy from the alternator might not be able to prevent the ultimate complete battery discharge, especially if the battery temperature is low.

The characteristics of various types of power profiles define the power management strategy. Subsystem loads fall in the following classes of power profiles:

- Profiles of near constant power. They often allow the variation of power between a lower and an upper power limit. The lower limit defines the power level at which the load is still useful or the power level with the device in a sleep mode. Examples are the lights in a vehicle. If an estimated number of hours of illumination are needed, power management has control over timing and power level. By comparing the power and estimated energy demand with the status of the battery, power management can time the switch-on and the power level to fit the calculated availabel energy and power from the battery during the planned time interval of operation.

- Cyclic or quasi-cyclic profiles. For these types of loads, proper timing of the variable load has an additional power saving effect. For example on/off operation can be used to operate another periodic load that is out of sync with the first one without increasing the use of power. Although the discharged energy is not reduced, the energy can sometimes be discharged at lower currents which yield higher battery capacity.

- Dynamic power profiles. Some subsystems transit through several stages of power within an operating cycle, producing power changes at irregular intervals, depending on circumstances. An example is an electronic subsystem that has displays, radio communication, radar, and needs electric power for mechanical equipment such as a missile launcher. At different times of the operating profile, when power switches of the system are activated, the power level for the subsystem changes.

Dynamic power profiles can be manipulated. For example, during the first three revolutions of a starter motor a lot of current is needed to overcome the initial friction of the motor. After two or three revolutions the friction is greatly reduced and the power levels are correspondingly lower. Therefore, it is customary to switch off all loads not needed at the time when the battery voltage is low, before activating the starter motor.

Likewise, if two discharged batteries need to be charged, it can be shown that staggering the charge time of the second battery, such that the high current charge occurs during the taper current period of the first battery, both batteries will be charged faster and at lower power levels.

All manipulations for power control in a vehicle have two objectives:

- The power profile for the combined loads (the compound profile), which are active at the same time, must not exceed the power available from the battery.
- The energy drawn during an operating cyclus is minimized.

To this end, the proposed power management scheme implements priorities for power distribution and arranges operating cycles, shutting down temporarily or reducing power to some subsystems while favoring others in a precise timing algorithm that optimizes the power distribution according to user and vehicle defined tasks.

In addtion, power management seeks to minimize the compound power profile (combined power of all operating subsystems) because a battery supplies significantly more energy if it is discharged at lower current (low power).

The proposed strategy is:

- Shifting load schedules and power peaks against each other
- Reducing power to subsystems to levels still compatible with the function and task of the subsystem
- Grouping the operation of subsystems, supplying power to some while shutting off power to other non-critical subsystems
- Assigning user defined priorities to the power distribution schedule

Micron's proposed power management system requires the following input:

- The state-of-charge of the battery that supplies the power to the subsystems
- A model of the battery to make scheduled loads compatible with available battery power and energy
- The power profiles of the electrical subsystems
- Operator input to schedule the use of subsytems

The state-of-charge provides the reference status for the power management plan. The Battery model allows the prediction of the available power and energy profile of the battery. The power profiles of the various subsystems that are connected to the battery serve as input for the arrangement of the power schedule and the time schedule of the loads on the vehicle.

DESCRIPTION OF THE SYSTEM HARDWARE

The NPC network consists of three components:

- The power network which supplies electric power to the various electric subsystems of the vehicle
- The wireless neural signal communication network that carries the neural control algorithm
- The sensor network that monitors the state parameters of the subsystem

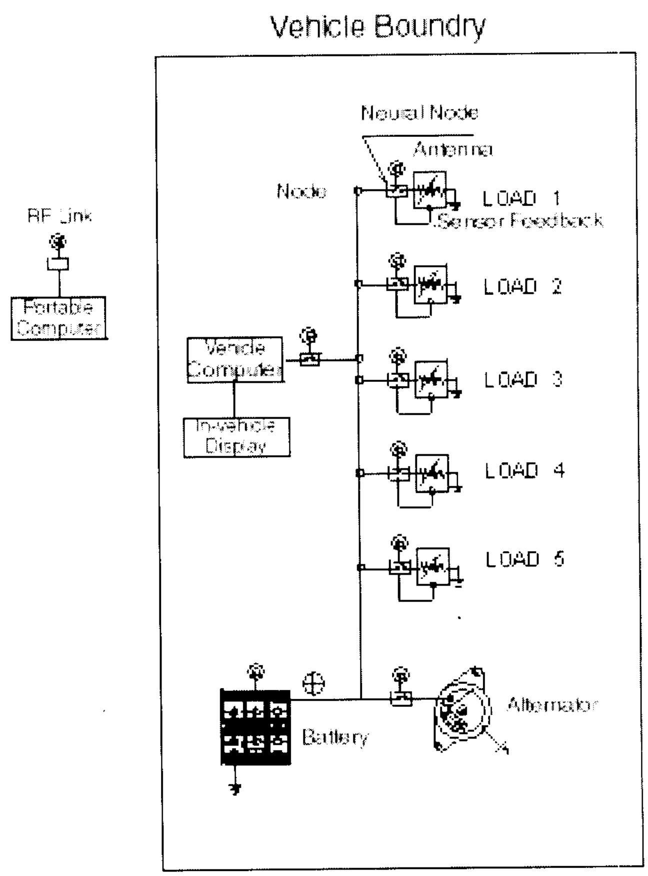

Figure 1: Simplified Block Diagram of the Neural Power Management System

The basic hardware concept is illustrated in Figure 1 in a simplified block diagram. As seen, the only substantial wire in the system is the wire of the power supply network, which provides power from the vehicle's battery and alternator to the respective electrical loads on the vehicle. The power wire is connected to the positive terminal of the battery. All electrical loads are connected in parallel to the power wire, which meanders through the vehicle from one load to the other. A negative wire is not needed since it can be assumed that the vehicle chassis is grounded and ground connections can be obtained by simply connecting the load locally to the chassis.

At each electrical junction on the power wire, subsequently called a "node", there is a highly integrated microprocessor-based smart control and data acquisition system that will be produced using MEMS technology. It regulates the power to the particular subsystem. It functions as a data acquisition and control system and as neuron of the neural network. The neuron receives its electric power from the power wire (optional from a small, local battery), but is otherwise a self-contained control unit with independent analysis and control logic that is specific to the subsystem it controls.

Each node includes a power control circuit. It controls the power to the load, to which the node is connected, according to the control signal produced by the corresponding neuron.

The neuron has several functions:

- It takes measurements of state parameters from the electrical subsystem for which it manages the electric power. The objective is to determine the state of health of the electrical subsystem and to detect pending failure at a time when it is not critical, i.e. when the vehicle is not on a mission. These measurements can simply be current and voltage measurements of the power supplied to the device, but may also include any electric transducer based measurements of parameters that define the function and state of health of the subsystem. Included, therefore, could be temperature, strain, pressure, vibration sensors etc. Alternatively, it could store digital status information directly submitted by the electronics of the subsystem.

- It filters the measurements and learns power profiles of the subsystem it controls, and generates, from the measurements, a reference profile that is used for power management. It analyzes the measured state parameters of the subsystem, comparing it with reference values that represent the healthy state of the subsystem.

- It produces electric control signals that control the power to the electrical subsystem. Control signals can range from simply on/off, to proportional power output with lower and upper operating limits, depending on the purpose and function of the device. Resistive, capacitative and inductive loads can be controlled. The trigger for the control signal can be internal, produced by the internal status analysis and control algorithm that resides in the neuron, or it can be external, communicated by other neurons or the vehicle's computer, or it can be in response to operator initiated commands.

- It provides wireless communication with other neurons in the vehicle; with the vehicle's computer, the in-vehicle displays and with the world outside the vehicle. As indicated in Figure 1, all signal transmission between neurons is wireless. There are only small local networks of signal wires connecting any particular neuron to the sensors on the electrical subsystem that the neuron controls. But there are no signal wires between neurons and from the neurons to the vehicle computer, or the operator, or the displays, or to the outside of the vehicle. Instead, each neuron has a wireless link, which can instantly establish differerent network configurations between the other neurons, and to the vehicle computer, that supervises the system of neural nodes and functions as a master controller.

It should be noted here that the neural control system, because of the wireless communication, is not restricted to the vehicle but could easily be expanded and set up for several vehicles which, individually, are platforms of a single more complex system such as a missile launch station which may consist of a separate missile launcher, a radar station and a guidance control center. While each of these might be attached to separate rolling platforms they are part of the same missile launch station. Since all neurons are identical hardware and are interconnected wireless, the connections between neurons are adaptive, which means the connections can change dynamically. Therefore neurons residing in different vehicles can quickly be interconnected to a single neural control system. This would be of interest if power is shared between several vehicles. In that case the power wires of the participating vehicles and the corresponding vehicle chassis need to be connected.

The RF link of each neuron can act as signal repeater or as direct communication link. Reliable communication with the vehicle computer and other neural nodes is secured, even in obstructed spaces, by handing down communication signals through repeaters.

The technology of the neuron is based on technology developed under contract to TACOM for a smart integrated battery controller[1], which communicates wireless with the vehicle computer. The present controller is based on an 8051 type 16-bit processor with 64k program memory and 512k data memory and an RF interface on board. This provides for very efficient programming and fast program execution. The CPU has a multiplier on board that generates 32 bit numbers in registers, which can be added. This allows for the implementation of very powerful digital filters. A 12 bit A/D converter with 8 channel multiplexer is on board the

CPU chip along with three independent timers and a high speed synchronous and an asynchronous interface. Signal conditioning circuits on board the controller accomodate various input ranges, from a few milli-volt to more than 18V.

The controller unit has several voltage regulators on board that can be independently shut down. This allows the reduction of power consumption levels in stages, down to a few microvolts depending on the desired operating mode (sleep mode, operation with RF off, or full operation). A 32kHz clock can be activated by the software to replace the normal 6MHz clock used by the microprocessor, further reducing, on demand, the needed power in the sleep mode of the controller.

This technology will be expanded to include a pulse width modulated (PWM) amplifier for current and voltage control. MEMS technology will further integrate the controller into a compact stand-alone data acquisition and control system that can be used in control systems, which employ massive parallel processing.

PWM technology was selected because, for this application, it offers an important advantage over linear power amplifier technology. While linear power amplifiers are very inefficient at partial loads, PWMs have an efficiency of 90% over a wide range of power levels, which reduces the need for cooling and saves energy. The output of a PWM is a pulse train and ranges between two levels: zero and supply voltage. The power is regulated by modulating the pulse width. Power regulation requires a small signal amplifier to close the control loop between the pulse output and PWM amplifier input and a filter is needed between the PWM amplifier and the load to smooth the output.

The number of neurons is equal to the number of electrical subsystems that are managed. The memory of each neuron contains the following:

- A reference power profile of the subsystem it controls
- A matrix of values indicating power and other limitations for the subsystem
- A weighted matrix which determines the priority of the subsystem within the management system
- The data "connections" of the neuron to certain specific other neurons within the management system
- A data acquisition and analysis program for measurements on the subsystem
- A program for generating PWM power at the subsystem receptacle
- A neural control program, which decides when the subsystem is switched on or off
- A RF communication program

The reference power profile provides a description of the power development during a typical operating cycle of the subsystem. It specifies peak power values, time intervals for various power levels and the total time of a typical operating cycle.

In a typical operation, an electrical subsystem could be connected virtually anywhere to the power wire via a neural node. This makes it easy to add new subsystems to the vehicle or exchange existing ones.

Even additional batteries, temporarily connected to boost power, could be accommodated by the control system by simply connecting the positive post to a neural node anywhere on the power wire.

The neuron is either an integral part of the electrical subsystem, such as is the case with a battery with a smart integrated controller, or it is a generic stand-alone device. In the case of the battery with a smart integrated controller, all needed sensors are already connected to the appropriate places on the subsystem, and the only connections needed to make it operational are chassis ground and the connection between the power wire and the neural node of the power wire.

In the case of the generic stand-alone device, in addition to the connections mentioned above, the sensor wires are connected to the sensors on the electrical subsystem and power output of the neural node is connected to the power input of the subsystem.

The control algorithms and the monitoring and analysis algorithms of the neuron are downloaded wireless together with an ID number from a computer outside the vehicle (see Figure 1). The ID number, which is labeled to the neural node or/and the subsystem itself and stored in the memory of the neural node, serves to identify the device for maintenance personnel and within the control system. Likewise, modifications in the software, that might be needed anywhere in the system, will be transmitted wireless from the outside using the ID number as an address.

Target nodes for communication during operation of the vehicle are also addressed via ID number. It is thus apparent that the system can accommodate a wide variety of electrical loads, can easily be expanded or modified and major changes appear only in the software of each neural node. The software can be downloaded by personnel outside the vehicle.

The vehicle computer functions as master controller. Its purpose is to evaluate the inputs from all neurons, compare status and power requests for each node with a set of rules and with the presently available battery power, and hand down commands that are initiated by the vehicle operator. In addition the master controller stores selected status and maintenance information of each electrical subsystem for recall by maintenance or planning personnel.

The link of the system to the world outside the vehicle is simply a portable computer with an RF link identical to that of a neuron (see Figure 1). To upload or download information, the technician walks to within a few yards of the vehicle with a handheld computer and presses a key. This will initiate the data transfer. Since he/she would not have to enter the vehicle and connect data transfer lines. maintenance and readiness determination of the vehicle will be very fast and efficient.

THE NEURAL CONTROL ALGORITHM

A key feature of the proposed power management system is the reference power profile.

Each neuron either has a reference power profile for the device it controls in memory, or it learns it during use of the subsystem. The power profile is continuously updated in a way that changes occur in the profile if predefined thresholds are surpassed a predefined number of times during the operation. Therefore moderate variation of the actual power profile or occasional variations will not affect the reference profile.

The function and purpose of electrical subsystems in the vehicle is associated with the performance of tasks and their effect on power consumption as given by the reference power profile. The performance of tasks may require the activation of single subsystems or groups of subsystems depending on the complexity and nature of the task.

If a command to perform a task is given by the vehicle operator or the vehicle system computer, then the corresponding subsystem or group of subsystems is turned on in a sequence that is defined by the control algorithm. The corresponding power profiles are superimposed.

Before the subsystems are turned on and to avoid that power demand outranges the available power, the algorithm checks if the superimposed reference profiles of all active subsystems fit into the prevailing power profile of the system as predicted by the battery model and the battery status determination. If a problem is discovered, then the algorithm determines if targeted power reductions, and shifting of individual power profiles and power peaks of the new subsystem group that was newly brought on-line, can solve the problem.

This investigation is governed by a set of predetermined rules that spell out the limitations for the manipulation of subsystem power profiles, according to the tasks they need to accomplish. These rules prevent changes in the reference power profile of a subsystem that would render the subsystem incapable of performing the assigned task.

If this procedure does not solve the problem, then this is wireless communicated to all other neurons which initiate a similar process of reference profile modification for all active tasks and subsystems simultaneously, using a Kohonen type neural network approach. This type of neural network scheme uses interconnects and information feedback with all members of the network. The result is a reorganization of the subsystems such that the input condition, the fitting of all reference power profiles into the system power profile, is accomplished.

This process may require the complete shut off of some subsystems and termination of active tasks. In this case, the priority matrix establishes a sequence for the shut off that aims to minimize damage to the system operation in the vehicle.

The work of the control algorithm does not stop with the successful initiation of a task. Throughout the operation of the system, the system power is monitored. If a shortfall in power occurs, then the previously described process of power distribution starts again and continues until power equilibrium is reached.

The control algorithm provides two types of information:

- the state of health of each subsystem, and
- how to distribute the power and energy available from the battery between the subsystems of the vehicle using the reference profile as base for the determination.

The status of a subsystem (i.e defining parameters of its condition) is continuously measured by the attached neuron through an integrated data acquisition system that is part of the neuron (Figure 1). The status parameter measurements are compared with a reference status stored in the neuron. The reference status represents the "normal" state of the attatched subsystem. The reference status of the subsystem is either uploaded from a computer outside the vehicle at the time when the subsystem is installed or it is generated in the neuron by measurements of the status parameteres when the subsystem comes online for the first time, assuming that at that time the subsystem is in "normal" operating condition.

The difference between the reference state and the measured state serves as state of health indicator of the subsystem. The analysis is done by the microprocessor of the neuron. If the comparison indicates a problem, then this is reported to the vehicle computer, which in turn reports it to the dashboard of the vehicle and simultaneously stores the information in memory to be available on demand by maintenance personnel.

The smart battery controller is part of the power distribution system. It resides inside each battery module that is part of the power system. The smart battery controller determines the SOC and status of the battery and updates parameter values for the battery model that is an integral part of the software of the smart battery controller [1]. These values are transferred wireless to the vehicle computer at predetermined time intervalls.

The vehicle computer contains the same battery model as the smart battery controller and uses the parameter values transmitted from the battery along with the SOC reported by each module to calculate the presently available power and energy from the battery for the whole system. If several modules make up the battery of the vehicle, then the vehicle computer integrates the information from each module into a compound battery model.

Load patterns are initiated by the vehicle engine and by the vehicle operator, who provides command input from the dashboard by pressing software switches. At the time the operating system is installed on the vehicle computer, the subsystem IDs and their correlation to dashboard switches is programmed into the memory of the vehicle computer by pairing switch IDs and subsystem IDs. If a command is issued by the vehicle operator, the command signal from the corresponding switch along with the switch ID is transferred to the vehicle computer. The vehicle computer then correlates the command to the proper subsystem ID and assigns the priority number "1" for power distribution between system components, which makes the delivery of power to the target subsystem the highest priority. The new priority "1" for a subsystem, issued by an operator command, along with the estimated power and energy values of the battery is transferred wireless from the vehicle computer to the neuron of the targeted subsystem.

Each neuron contains four matrices: one describes the power distribution priorities among the subsystems of the vehicle. This is essentially the weight matrix of the neural system. Another describes the measured status of the subsystem and a third contains the reference status of the subsystem. A fourth contains the power limitations of the subsystem that are used for power management.

Each neuron has a complete set of values in the weight matrix that describes the priority distribution among all the subsystems of the vehicle. An initial set of priority numbers in the matrix, defining a default priority matrix was either stored when the operating system was installed, or is generated as result of a learning process during the use of the subsystems in the vehicle.

If power and energy equilibrium between demand and supply is established the resulting power configuration are selectively stored in a library in memory of the vehicle computer and serve as reference configurations. The next time a change is requested by the operator or the vehicle, the vehicle's computer searches in memory for the associated power profile, which if available, is then sent to all neurons which consequently respond with the appropriate power mode.

Thus, the system learns from experience, the configurations of loads, and how to optimize each load configuration that represents a new experience.

A priority "0" in the priority matrix means that the system is shut off. Communication between neurons and the vehicle computer takes place between neurons that have nonzero values in the priority matrix. Therefore the communication pattern changes with the operating conditions.

CONCLUSION

As the transformation of military technology into smart battlefield systems progresses, severe power shortages occur on-board the moving platforms that carry these systems. Micron's research has shown that power management on board the vehicles can increase available power and energy by utilizing an intelligent distribution algorithm. It shifts the discharge of the battery to lower currents and shifts power profiles of subsystems against each other, in such a manner that power peaks of the compound power profile are minimized. Furthermore, research has shown that single chip microprocessor-based data acquisition and control and RF communication, along with the integration of PWM based power electronics using MEMS technology, make it economically and technically feasible to use massive parallel processing and a neural network technology. It is better able to solve the complex control problem of optimum power distribution and subsytem state-of-health determination than linear control methods. MEMS technology integrates the components and dramatically reduces the cost of neurons in the network. The application of RF as a means of communication between neurons facilitates the dynamic configuration of the neural network during the operation of the subsystems, with a corresponding increase in the performance of the network. It permits the direct control of power at the location of each electric subsystem. This allows the reduction of the power harness, to essentially a single wire, with corresponding savings in installation cost, maintenance and repair cost, and vehicle weight. The success of power management hinges to a significant degree on an accurate battery model, which yields the state of charge of the battery and predicts power and energy development during discharge with dynamic currents.

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